Available online at www.sciencedirect.com
ScienceDirect
Renewable and Sustainable Energy Reviews
12 (2008) 564–574
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

Renewable energy options for a Sahel country: Mali

A.S. Maiga, G.M. Chen*, Q. Wang, J.Y. Xu

College of Mechanical and Energy Engineering, Zhejiang University, Zheda Road 38, Hangzhou, Zhejiang 310027, PR China

Received 15 May 2006; accepted 31 July 2006

Abstract

This paper presents a critical appraisal of renewable energy options for Malian modern energy technologies. A critical review of different renewable energies is presented, some comparisons between the country and other Saharan countries are listed. The study shows that Mali energy is very poor compared with other Saharan countries and the level of firewood energy is very high and the one of modern energy is very low. The study also shows that only 10% of Malians have access to electricity, the rest depend on wood, charcoal, kerosene, and petrol for their energy needs. In term of renewable energy used, Mali's balance is better than some Saharan countries. That way can be appreciated just for the new promotion and sustainability of renewable energy policy targets of the country. As a poor Country Mali can more exploit it renewable energies to combat the poverty and especially in rural zone with very low rate of electricity about 1%. The utilization of the renewable energies can also be a good opportunity to fight the desertification and dryness in Mali which is about 60% of Malian territory.

Keywords: Renewable energies; Modern energy; Sahelian countries; Desertification; Mali

Contents

*Corresponding author. Tel.: +86 571 87951680; fax: +86 571 87952464.
E-mail address: gmchen@zju.edu.cn (G.M. Chen).

1364-0321/$ - see front matter
doi:10.1016/j.rser.2006.07.005

1. Introduction

Mali is one of the largest Sub-Saharan countries located in the middle of West Africa region, just at the southern edge of the Sahara desert with largely farming and pastoral rural communities. It covers 1.204 millions km^2 which 60% are desert with high temperature and high wind velocity. The total population of the country has passed 11.7 million (2000), of which 79% live in rural areas.

Like many Saharan countries, energies carried by biomass are still the major sources of energy in Mali. In 2000, the final energy supplied was 2.93 million tons of oil equivalents (TOE) successively divided as follows: 72% from woodfuels, 14% from hydrocarbons, 10% from agriculture, 3% from coal, and 1% only for electricity [1]. The total energy consumption was 0.462 Tetrawatthour (TWh) of which 0.2 TWh is from fossil combustibles and 0.262 TWh from hydropower [2].

The final energy consumption per capita was 178 kg of oil equivalents (kgoe) with modern energy (electricity and oil products) accounting for 19 kgoe. The per capita of modern fuel for Mali is very low compared to some Sahelian African countries such as Senegal (102 kgoe), Gambia (87 kgoe), Niger (36 kgoe), and Burkina Faso (33 kgoe) [3]. However, in most rural areas, up to 90% of the total energy consumed is derived from biomass sources. Only 1% of the rural population (about 80% of the total) is estimated to have access to electricity even in the urban areas the access is only over the average of 65%. This energy balance of Mali shows the overwhelming dominance of traditional biomass (over 90% of total energy consumed) with electricity contributing as low as 1%. Only 10% of the total population has access to electricity. This shows that there is a formidable task required to electricity in the rural areas.

2. Background of energy and development

Energy has always played an important role in human and economic development and in society's well-being. For example, fuelwood has been used from immemorial time to make fire, and the first civilizations were already making use of wind in sailing over seas. Wood was then abundant and free. People lived in small tribes and it was only when villages and small cities emerged that fuelwood became a traded and forests started to be overexploited to the extent that in some areas a shortage of wood became apparent. Access to electricity and other modern energy sources is necessary, but not sufficient requirement for economic and social development. Economic development, both in rural and urban, large and small-scale, can also be promoted and encouraged by making production processes more efficient, thereby making the final-products more affordable.

Roughly 1.6 billion people, mostly in the developing countries of the world, are quoted as lacking of access to basic electricity services [4]. Access to electricity is a fundamental component of economic and social development and therefore of great importance to these populations. The lack of electricity deprives people of basic necessities such as refrigeration, lighting, and communications. The economic development of modern societies is crucially dependent on energy. Energy is vital for sustainable development. It is used to generate electricity for a variety of needs, among which are domestic, transportation, and industrial needs.

In Mali, about 90% [1] of the population still does not have access to electricity. Most of the people live without power in rural area. The climate is dry and hot with intense solar radiation 5–7 kWh/m^2/day and high wind speed about 3–7 m/s in the north and 90% of Malian depends on agriculture for their living. Renewable energies, therefore, are a good potential source of electricity.

Energy also plays a critical role in sustainable human development. It impacts on poverty, population, health, the environment, industrial investment, agricultural and socio development of a nation. The provision of energy services has been long time a central role in economic development. Indeed there is a direct relationship between the absence of adequate energy services and poverty indicators such as infant mortality, illiteracy, life expectancy and total fertility rate [5]. The key challenge facing the African energy sector is the provision of modern energy services to over 60% of its population, to facilitate economic development and poverty alleviation.

3. Brief review of renewable energies technologies

Renewable energy sources made their first real entry onto the international energy scene in the 1970s when the two worldwide oil crises occurred. The importance of renewable energy particularly in recent years, with the pursuit of a sustainable global pattern of energy supply and use, it has been widely acknowledged that renewable energy sources must be a key role.

Renewable energy has the potential to respond to global sustainability and environmental, safety, social and economic goals in the Sahel desert countries. Renewable energy resources including biomass, geothermal energy, hydropower, ocean energy; solar energy, wind energy, and hydrogen have several important characteristics like site specifity, variable availability, diffuse energy flow, and low or no fuel cost. Mali as many Africans countries depends a great deal on renewable energy sources mainly for cooking, drying of agricultural products and others.

3.1. Solar heating and cooling

The World-wide in low and medium-temperature solar heating has been strong for several decades. The technologies involved are not complex and market has been very successful in some Asian countries, Australia and Mediterranean region. Buildings can be designed to use efficient solar collection for passive space heating, water heating, and cooling using absorption chillers or desiccant regeneration [6].

Economics and system reliability have acted as constraints to wide commercialization. These technologies have some good opportunities:

- low temperature heat (hot water, space heating, swimming pools),
- drying processes,
- industrial heat,
- cooling and ventilation of building and food conservation by sorption (adsorption, absorption, desiccant cooling),
- lighting,
- passive solar through design.

3.2. Solar concentrating collector

High temperature Concentrating Solar power systems hold good promise for electricity generation and perhaps for hot water. These technologies include parabolic troughs, central receivers and parabolic dishes. In this area one square kilometer of land is enough to generate 125 Gwh/year from a 50 MW plant [7]. Thus, about 1% of the world's desert areas could be theoretically sufficient to meet the world's electricity demand [8].

One of the most interesting advantages of this technology is that it can provide power on demand, through the storage systems involved. The technology can also be combined in hybrid form (with fossil fuel boilers) to improve flexibility and costs.

3.3. Photovoltaic

The PV solar options is showing great promise and there is increasing interest in the technology as costs continue to come down and market deployment grows.

The role of photovoltaic generated ranging from water pumping, domestic supply, street lighting telecommunication networks. Commercially available solar PV modules are up to 20% efficiency and generate electricity for between 20 and 32 cents/kWh in highsunchine [6]. Experimentally the photovoltaic technology cells have laboratory efficiency up to 37, but the investment is very high for the poor rural people. Work on reducing the cost of manufacturing, developing new materials such as quantum dots and nano-structure, and using low-cost polymer materials, will allow this resource to be more fully exploited [8].

This technology can be a good opportunity in the Sahel countries due to the fact that most homes in rural area are still not connected to the national grids. The technology has high potential in many remote regions of the world that have poor access to energy process. PV is seen in many countries as a clean sustainable energy option that can help address climate change and other environmental concerns.

3.4. Wind energy

Wind energy is one of the big success stories in our effort to develop sustainable energy options. The global installed wind energy capacity reached 40 GW [9]. The average size of wind turbines 25 years ago was less than 50 kW, whereas the largest is now approaching 5 MW with rotor diameters of 125 m, the average turbine size is currently 1.6–2 MW [8].

In addition to the energy and environmental benefits, the wind energy commercialization is providing economic and industrial benefits and nowadays the capacity factor of wind electricity is between 20% and 30% [10].

3.5. Hydropower

Hydropower now provides over 20% of the world's electrical generation and there is potential to double this contribution (IEA presentation). Hydropower projects under construction will increase the electricity share by about 13% for a total electricity share of just under 20% [9].

The major problem for hydropower, especially when it comes to additional capacity needs a long lead period required for projects approvals through the public and financial acceptance process. Nowadays hydropower is currently burdened with environmental (river and stream aquatic life) and social (displacement of populations) issues. It capacity factor is around 35–60% [10].

3.6. Bioenergy

Biomass sources include, agricultural and livestock residues, short rotation forest plantation, municipal solid waste, and other organic waste streams. There are used as feedstock to produce solid fuels (biogas, synthesis gas, hydrogen) [11]. These fuels can then be converted to electricity, heat, transport fuels, chemicals, and materials.

Bioenergy covers a wide spectrum of energy activities, from the direct production of heat through combustion of fuel wood and other biomass residues to the generation of electricity, the production of gaseous and liquid fuels and chemicals. It is widely used throughout the world. In Sub-Saharan countries, biomass in the form of fuel wood, agricultural residues are often the most common fuels for cooking and heating. The estimated contribution of bioenergy to global energy supply is of the order of 12–14% of a total primary energy [11]. Biomass can play a dual role in greenhouse gas mitigation related to the objectives of the Kyoto protocol and other climate changes initiatives. It can act as a source of sustainable energy to substitute fossil fuels and as a carbon store. Modern bioenergy options offer significant, cost-effective and perpetual opportunities towards meeting emission reduction targets while providing additional ancillary benefits arising from the wide occurrence of biomass materials. It is important to notice that the area of bioenergy holds significant promise for technical improvement and particularly in the Sahel counties. Presently the biomass energy (electricity, heat, ethanol) has a capacity factor between 25% and 80% [10]. Research on artificial enzymes to hydrolyze biomass, on fermentation organisms to remove contaminants from synthesis gas is needed to take care, greater advantage of the biomass.

3.7. Geothermal

The geothermal resource is the internal heat of the earth. The use of this indigenous and environmentally friendly resource covers a large range of options from power

generation to space heating and air conditioning. In terms of global electricity production, geothermal power plants produce over 42 TWh/year through a total installed capacity over 7000 MWe [12]. Geothermal electricity is very efficiency, around 45–90% [10].

3.8. Hydrogen

Hydrogen today is primarily used as a chemical feedstock in the petrochemical, food, electronics, and metallurgical processing industries, but is rapidly emerging as a major component of clean sustainable energy systems. Hydrogen can provide a significant benefit to the electricity supply market for baseload (geothermal) seasonal (hydroelectric) and intermittent (PV and wind) renewable resources. Coupling these renewable-based electricity generation technologies with hydrogen storage helps maximizing dispatchability and reduce the impact of low capacity factors by providing electricity and fuel when and where it needs. Efficient and cost-effective hydrogen storage is key to achieving the benefits of this approach to providing renewable power on demand.

4. The potential and characteristics of renewable energy in Mali

Renewable energy sources are often carbon-free energy source. Renewable energy sources include hydropower, wind power, biomass and solar energy. The most popular renewable energy is hydropower which supplies nearly 5% of the electricity in the world. Among about 1000 MW hydropower only 300 MW are installed, producing 70% of Mali's electricity. Wind power is already commercialized. Biomass is used in many places and especially in Sub-Saharan countries and represents about 90% of Mali's total energy. Bagass from sugar cane industries can be used for cogeneration and ethanol for transportation, 10 million tones per year of cotton stalks in southern zone of Mali can be used in gasiefier or sterling engines, Jatropha can supply vegetable oil for transport needs. Solar energy is a promising renewable energy in Mali, with 5.7 kW/m^2/day and 2500 h annual solar radiation. Wind energy can be very useful in the northern part of the country with wind speed 3–7 m/s. Renewable energies have many benefits for developing countries and particularly for Sahel countries with low per capita energy. These benefits are:

- reduced emissions of greenhouse gases, air pollutant, and hazardous wastes,
- reduced reliance on imported energy, if we know all Sahel countries have to import their energy,
- no risk of fuel price hike,
- increased local job and business opportunities,
- contribution to local economy through payment of property taxes and land rents.

5. Energy and poverty

About 2 billion people currently have no access to affordable energy services, with 30 millions people being added to this figure annually in the developing countries. Improved access to clean modern energy in developing countries including Mali is a fundamental step to poverty reduction. About 2.4 billion, notably in rural areas of Asia and Africa depend, on traditional biomass in the form of firewood, charcoal, harvest residues and dung for cooking and heating. About 35% of the energy typically derives from these sources. In

Mali it reaches about 90%. As a rule, this biomass is burned with low efficiencies of only 10–15%, while high levels of indoor pollution from open fires lead to health problems of the person exposed, mostly women, children and the elderly. Modern energy services enhance the quality of the life of the poor in countless ways. Electric light extends the day. Refrigeration allows local clinics to keep needed medicines on hand and some vaccines. A modern energy can directly reduce poverty while the extensive uses of biomass in traditional and inefficient ways restrain economic and social development of the country.

6. Impacts of renewable energy using in developing countries

The use of renewable energies in developing countries and particularly in Mali can change some poverty indicators like:

6.1. Poverty and hunger

Clean energy helps people light their homes, increasing economic productivity. Using solar water pumps can free time from water collection, increasing productivity in other areas. It can also facilitate irrigation, increasing agricultural productivity and decreasing hunger.

6.2. Increasing education level

Renewable energy sources increase access to education and communication materials. Lighting in schools facilitates education and allows for night classes. It can help heat or cool school, making it easier and safer to educate students.

6.3. Promote gender equality

Using solar energy to facilitate water collection can increase free time for women to undertake other activities. Having indoor lighting can allow women to study at home.

6.4. Reduce child mortality

Renewable energy can make it easier to cook food, increase access to clean water and reduce indoor and outdoor air pollution. All of these improvements can easily improve health in young children. It is also vital for rural health, clinics and can also increase access to vaccines and other medicines important for children health.

6.5. Improve maternal health

Clean energy makes homes healthier, with clean water, cooked food, and lower air pollution. Electricity can also increase access to medical services.

6.6. Combat disease

Energy can improve medical facilities and access to medicine, including critically needed refrigeration of vaccines. Clean energy can also facilitate education about some diseases and ways to prevent them.

6.7. Environmental sustainability

Clean energy can be used for cooking and to pump and purify water without contributing to air pollution. Renewable energy will reduce the negative impacts of the use of traditional sources of energy, like wood, which leads to erosion, reduced soil quality, and desertification. It also reduces global carbon emissions, lessening the impact of climate change.

6.8. Development issue

Clean energy can facilitate communication, education, and job creation.

7. Traditional energy role on the deforestation and land degradation in Mali

As many developing countries, firewood is the major source of cooking and heating fuel for most rural communities and for the majority of urban in Mali.

In the developing countries as a whole, about 2 billion people rely solely on fuel wood as their energy source for heating and cooking [13]. Traditional fuels, mostly firewood supply about 52% of all energy required in sub-Saharan Africa [14]. The fossil-fuel utilization presently adds about 7 billion tones of carbon to the global atmosphere every year [15].

Table 1 gives out the energy balance of some Sahelian countries and their percentage of the traditional energy in the balance. From the table it can be seen that the percentage of traditional energy on the balance is very high and the general balance of these countries is very low.

In many developing countries, already the demand for fuelwood is far greater than the supply.

In Mali, wood consumption is estimated at 5 million tons per year, representing an annual deforestation rate of nearly $4 \times 10^9\,m^2$ [13].

Table 2 gives out the fuel used for cooking in rural area in some Sahelian African countries. From the table we can see that in Sahelian countries, firewood is the most used fuel which can be very dangerous for the environment of these desert countries. It can also see from the table the inexistence of electricity in the rural area for cooking.

8. Renewable energy policies in Mali

Worldwide, at least 45 countries have policy targets for renewable energies. Ten of these have been introduced as developing countries including Brazil, China, Dominican Republic, Egypt, India, Korea Malaysia, Mali, South Africa, and Thailand [16].

Table 1
Energy balance and traditional energy consumption in some Saharan countries [5]

Country	Total energy consumption (million Toe)	Traditional energy (%)
Burkina	1.7	91
Gambia	0.263	90
Mali	1.8	90.4
Niger	1.1	80

Table 2
Fuels used for cooking in rural households for some Sahelian countries [9]

Country	Firewood (%)	Gas, kerosene (%)	Charcoal (%)	Electricity (%)	Others (%)
Burkina Faso	91	2	4	0	0
Gambia	97	1	1	0	1
Mali	97	0	0	0	3
Niger	90	1	0	0	9
Senegal	84	1	12	0	1

Mali's energy policy has four major objectives:

- enabling access of the largest portion of the population to modern energy at an affordable price,
- protecting and preserving existing fuel wood resources,
- realization of the national energy resources potential,
- establishment of efficient strategies for the energy sector and its different sub-sectors [17].

Mali has some good potential opportunities for using renewable and environmental energy technologies for energy service provision in rural and urban areas. A low level of electrification, the establishment renewable energy sector and the government reform are all factors that favor such an approach.

The energy sector is mostly based on traditional fuel, with a low per capita consumption (0.3 tons oil equivalent). Ninety percent of energy consumed comes from the unsustainable use of fuelwood and charcoal, leading to accelerated desertification. Biomass producing surface has been disappearing at a rate of $9 \times 10^7\,m^2$/year, leading to soil erosion and desertification, and making this the predominant environmental issue linked to energy consumption.

The modern energy services come about 70% from hydropower and the rest from thermal power plants mainly in urban centers; car batteries and a few thousand PV installations supply some people in off-grid rural areas. In 2000, electricity represented just 1% of the country's energy balance while the fuel for thermal power plants and transportation had a cost of USD 100 million for the same period [18].

The National Water and Energy Directorate (DNHE) is Mali's primary governmental tools for implementing national energy policy, regulating the energy sector and the planning of large energy and water projects. It oversees various projects such as the national program for the promotion of butane gas, the special energy program (PSE) and the domestic energy project.

Some government energy organizations and their activities on energy policies are:

- DNHE for the implementation and regulation of national energy policy and planning of energy and water projects.
- energy Mali (EDM) national electricity company for production and distribution of electricity and the support for development of new energy generation projects.
- national Center for Solar and Renewable energies (CNESOLER) for research, development and promotion of renewable energies.
- national Directorate of Agriculture for the promotion of biogas.

Table 3
Data installed capacities of PV and Wind systems in some Saharan countries [4]

Countries	Water pumping	Telecom and radio	Community TV/video	Refrigeration/ health center	Solar village lighting
Burkina Faso	100	150	50	30	3
Mali	350	500	3000	40	—
Mauritania	50	—	50	—	—
Niger	120	100	1200	100	—
Senegal	50	—	50	—	—

Table 3 gives out the renewable energy system installed in the rural area of some Sahel countries. From the table we can see the installed potential of Mali is better than that of other Sahel countries due to the policy targets for renewable energies policy introduced in the country.

9. Conclusions

In general, the characteristics of the Malian energy sector can be summarized as follows:

- there is high dependence on fuelwood for domestic energy needs,
- there is high incidence of waste and underutilization of agricultural waste as a source of energy,
- there is increasing use of fuelwood in relation to other source energies,
- only about 10% of the population is connected to the national electricity in urban area and only 1% in rural area.

Access to essential energy services will need to increase for the Millennium Development Goal targets to be met. In some instances, renewable energy technologies can meet the needs that conventional approaches cannot. In other way, renewable energy technologies can provide comparable services more readily than conventional services and at comparable costs.

In Mali renewable energies can be a good solution for the energy crisis since it has very limited reserves of oil and natural gas, and it is an importing oil and gas country. Mali government needs to develop the renewable energies sector to increase the rate of electricity in the country and especially in the rural areas which is the lowest in the world.

References

[1] Solomani Diakite Mali Energy Sector Development: Opportunities for Cooperation Third meeting of the global forum on sustainable energy development Graz, Austria, 2002.
[2] USA. CIA world Factbook, 2002.
[3] Energy Statistics of non-OECD countries. International Energy Agency Publication, 1999.
[4] The World Bank 1996. Rural Energy and Development: Improving Energy Supplies for two Billion People, Washington DC, 1996.
[5] International Energy Agency: World Energy Outlook, 2000.
[6] US Climate Change Technology Program; 2003.

[7] Philibert C. Case study 1: concentrating solar power technologies. International Energy Technology Collaboration and Climate Change Mitigation, OECD Environmental Directorate, IEA, Paris; 2004.
[8] Robert N. Schock energy technologies for the 21st century—the roles of renewable energy; 2005. p. 6–7.
[9] World Energy Council 2004a. Survey of Energy Resources, World Energy Council, London; 2004.
[10] Goldemberg J. (Chief Editor). World Energy Assessment: Energy and the Challenge of Sustainability, United Nations Development Program (UNDP), 2000.
[11] Sims REH. Sims, Biomass, Bioenergy, and Biomaterials—future prospects. Biomass and Agriculture: sustainability, markets, and policies, Organization for Economic Cooperation and Development, 2003, Vienna. p. 37–61, ISBN:92-64-10555-7, 2004.
[12] World Bank, Kenya country brief, 2002.
[13] World Resources Institute, World Resources Report, 1994–95 New York: Oxford University Press, 1994, p. 33.
[14] World Resources Institute. World Resources, 1994–95. New York: Oxford University Press; p. 10.
[15] Pacala S, Socolow R. Stabilization wedges: solving the climate problem for the next 50 years with current technologies. Science 2004;305:968–72.
[16] World Bank, Africa Technical Department, Review of Policies, Strategies, and Programs in the Traditional Energy Sector. In: Proceedings of Workshop 11, Ouagadougou, Burkina Faso, February 21–25, 1994 (Working-level translation from French). p. 28, 48, and 77.
[17] World Bank, Africa Technical Department, Review of Policies, Strategies and Programs in the Traditional Energy Sector. In: Proceedings of Workshop 1, Bamako, Mali, May 10–12, 1993 (Working-level translation from French, 1993). p. 23.
[18] Country Report Mali 1stquarter 2000.